CLIMATE CHANGE IMPACTS ON RUNOFF, SEDIMENT, AND NUTRIENT LOADS IN AN AGRICULTURAL WATERSHED IN THE LOWER MISSISSIPPI RIVER BASIN

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ABSTRACT. *Projected climate change can impact various aspects of agricultural systems, including the nutrient and sediment loads exported from agricultural fields. This study evaluated the potential changes in runoff, sediment, nitrogen, and phosphorus loads using projected climate estimates from 2041-2070 in the Beasley Lake watershed in Mississippi, USA, using the Annualized Agricultural Non-Point Source (AnnAGNPS) pollution watershed model. For baseline conditions and model inputs an earlier validated simulation of the watershed was used with an event-based NSE of 0.81 for runoff and 0.54 for sediment without calibration. Fifteen global climate models (GCMs) for the climate change scenario RCP8.5 in Western Mississippi were used. Daily precipitation and air temperature were generated with the weather generator SYNTOR. Daily climate data derived from all 15 GCMS were used in AnnAGNPS simulations to generate ensemble projected loads, and climate data from four GCMs were used in simulations to assess the effectiveness of five different conservation practices for reducing projected loads. Predicted median annual-average pollutant loads increased by 9% to 12% with ensemble projected climate change. However, no-tillage and cover crop conservation practices were predicted to reduce pollutant loads from 20% to 75% below historical levels despite the impacts of climate change. This study suggests that greater implementation of conservation practices can be effective at mitigating water quality degradation associated with projected climate change.*

Keywords. *AnnAGNPS, CMIP5, Soybean, SYNTOR, USDA-CEAP, Water quality.*

Climate change has the potential to affect agroecosystems through rising temperatures, altered precipitation patterns, and elevated atmospheric carbon dioxide concentrations (Porter et al., 2014; Romero-Lankao et al., 2014). While there may be some positive outcomes for agriculture from these changes, such as a longer growing season or carbon dioxide fertilization of crops, current research suggests that projected changes in climate will likely cause greater soil erosion and further water quality degradation due to projected increased intensity in rainfall events (Nearing et al., 2004; Paerl and Huisman, 2009; Whitehead et al., 2009; Yasarer and Sturm, 2015). A critical region for the study of climate impacts on agriculture is the Lower Mississippi Alluvial Plain (i.e., the Delta), a highly productive agricultural region of the United States that drains into the Mississippi River. National climate change studies project that this region may receive increased precipitation in winter and spring, but decreased precipitation in summer and experience an increase in the frequency of extreme daily precipitation events (20-year events) up to three times as often compared to the 1981-2000 time period (Walsh et al., 2014).

Reduction of non-point source pollution is an important water quality management goal in the Mississippi Delta. It is estimated that nitrate-N concentrations in the Lower Mississippi River have increased, on average, over ten-fold from pre-development conditions to 1980-1998, and total nitrogen has approximately doubled in the same time period (Goolsby and Battaglin, 2001). By some estimates, per hectare nutrient and sediment loads delivered from the Lower Mississippi River Basin are much higher than loads from other basins, partially because this region lags in the use of conservation practices compared to other regions in the Mississippi River drainage system and also due to the high annual rainfall typical of this region (NRCS, 2013). However, total loads are much higher from areas in the Upper Midwest (Goolsby and Battaglin, 2001; Shields et al., 2009). Runoff from Delta watersheds flow into the Mississippi River and ultimately the Gulf of Mexico, where a large hypoxic area has persisted since the early 1980s and continues to threaten

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aquatic habitats and fisheries (Turner et al., 2008). Mitigation of the hypoxic zone has been a national priority and has initiated the development of the Mississippi River/Gulf of Mexico Hypoxia Task Force led by both federal and state agencies. While the task force struggles to meet current nutrient reduction goals, it is important to consider how climate change can affect water quality loads from agricultural watersheds in the future.

Conservation practices are an important component of water quality management in agricultural watersheds that can potentially offset impacts from climate change (Delgado et al., 2011). Previous studies have demonstrated that a combination of conservation practices can potentially reduce soil erosion and sediment yields associated with climate change (Garbrecht et al., 2015; Parajuli et al., 2016). Recommended conservation practices for both improving water quality and soil carbon sequestration include conservation tillage and no-tillage, diverse crop rotations, cover crops, effective nutrient management, crop conversion to natural land-use, and riparian buffer or vegetative filter strip implementation (Delgado et al., 2011; Jayakody et al., 2014). In addition to water quality benefits, agronomic studies in the Mid-South have shown that conservation tillage is effective at increasing soil organic carbon and nitrogen content, while improving water infiltration and retention (Locke et al., 2010). Certain practices may be more effective at improving water quality depending on watershed conditions and dominant hydrologic patterns. Simulation analysis can help determine the relative effectiveness of conservation practices in buffering against climate change impacts and provide useful guidance for regional conservation implementation and future studies.

National and regional-scale studies are important for understanding general patterns of climate change, but teasing out local impacts is essential to developing relevant mitigation strategies. This study evaluates the potential impacts of climate change on water quality loads and the effectiveness of conservation practices on soybean cropland in the Beasley Lake watershed (BLW), a small watershed located in Sunflower County, Mississippi, within the Lower Mississippi River Basin (fig. 1). The selected watershed is a study site for the United States Department of Agriculture (USDA) Conservation Effects Assessment Project (CEAP) and detailed historical data are available. Objectives are to assess potential climate change in the Delta region of Mississippi using 15 GCMs; evaluate the impacts of climate change on runoff, sediment, and nutrient loads using the AnnAGNPS model; and to evaluate the effectiveness of conservation practices to reduce sediment and nutrient loads under climate change. An evaluation of uncertainty is included with each objective by considering the differences in the GCM projections. Knowledge on impacts and resiliency of management practices from this study can be extrapolated to surrounding Delta watersheds to provide initial guidelines for developing regional climate adaptation strategies.

Materials and Methods

Climate Data Input Development

Projected climate data from 15 Global Climate Models (GCMs) from the Coupled Model Intercomparison Project (CMIP5) were used in this study (table 1) (Taylor et al., 2012). Models were selected based on availability of projected climate data for Representative Concentration Pathway (RCP) 8.5 and to represent a variety of potential climate conditions. The selected models include the full range of equilibrium climate sensitivity (ECS) and transient climate response (TCR) values. TCR is the temperature change at the time of CO_2 doubling and ECS is defined as the temperature change after the system has reached a new equilibrium

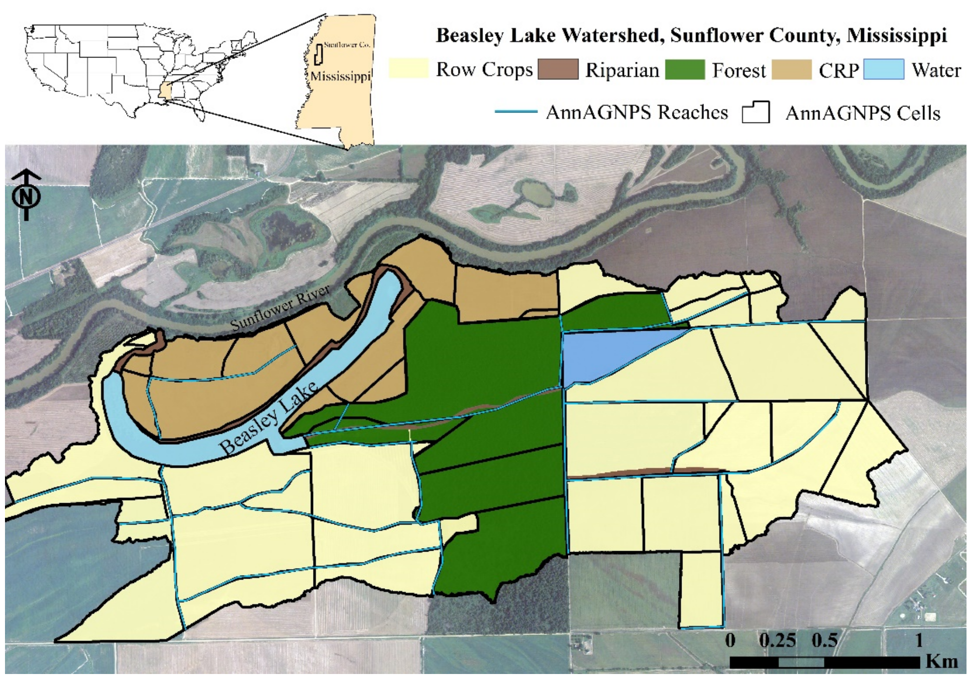

Figure 1. Location of Beasley Lake Watershed in Sunflower County, Mississippi, and the watershed subdivision into AnnAGNPS cells (subcatchments) and reaches (concentrated flow paths).

for doubled CO_2 including any additional feedbacks (IPCC, 2007). Within the ensemble of models used in this study the highest and lowest ECS values are represented with the MIROC-ESM and GISS-E2-R models, respectively. The term “Representative Concentration Pathway” (RCP) refers to the most current set of scenarios used by the climate change community for projected climate modeling (Moss et al., 2010). The four potential RCPs represent a broad range of emission scenarios available in the literature; however, the word “concentration” is used to emphasize the resulting greenhouse gas concentrations in the atmosphere, rather than emissions. The four pathways include radiative forcing levels of 8.5, 6, 4.5, and 2.6 W/m^2 by the end of the century (Van Vuuren et al., 2011). In this study RCP 8.5 was selected as the climate forcing scenario because it represents the greatest greenhouse gas concentration and the largest degree of warming for evaluating the effectiveness of conservation practices.

The bias-corrected and spatially downscaled BCSD-CMIP5 multi-model ensemble dataset was downloaded for the 12 × 12 km (1/8°) grid that fully contained Beasley Lake watershed from the “Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections” website (Maurer et al., 2007; Reclamation, 2013; available at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/). While the GCMs generally simulate historical climate with high accuracy, once downscaled on a smaller spatial scale the mean and deviation can differ slightly from observed data at the watershed level (Wang et al., 2014; Garbrecht and Zhang, 2015). To remove this localized bias, the monthly mean temperature and precipitation were adjusted using corrections factors, which were, respectively, the addition of the difference between average monthly reference and projected temperature, and multiplication by the ratio between reference and projected average monthly precipitation. The adjustment procedure ensured that the historical GCM data matched the mean and deviation of the observed historical climate values from the watershed; this process is called alignment (Garbrecht and Zhang, 2015). The time period used for alignment was 1971-2015; the adjustments applied to match the historical time period were then projected forward to data from 2040-2071.

GCM projected climate statistics for the 2041 to 2070 time period were used to temporally downscale projected monthly data to a daily time step. The downscaling procedure used the USDA synthetic weather generator, SYNTOR version 3.5 (Garbrecht and Busteed, 2011). SYNTOR is a stochastic daily weather generator that generates a time series of daily precipitation, minimum and maximum air temperature, and solar radiation that either represents historical conditions, seasonal weather forecasts, or climate change projections. Precipitation is generated independently from the other weather parameters. It relies on a Markov chain-exponential model to determine the occurrence of a rainy or rain-free day. The amount of rainfall is represented by a mixed exponential distribution. Minimum and maximum air temperature are generated with a multivariate model using the mean and standard deviation of variables conditioned on the wet or dry day status (Garbrecht and Busteed, 2011).

Two hundred years of daily weather data were generated in SYNTOR to represent the historical (1971-2015) time period and then used in AnnAGNPS to generate cumulative probability plots of baseline water quality loads. Two hundred years of daily weather data were also generated to represent projected (2041-2070) climate conditions for each GCM. The 200 years of daily data from each GCM were then used in AnnAGNPS to generate cumulative probability plots of runoff and water quality loads with climate change. The 200 years within the climate dataset represent the variation in conditions based on the monthly mean of the climate parameters for each historical or future climate scenario and the statistics derived from the historical dataset. Historical daily precipitation and minimum and maximum temperature data were extracted from the Global Historical Climatology Network (GHCN) climate station at Moorhead, MS (GHCND:USC00226009; 33.45°N, 90.5167°W), which is approximately 10 miles northeast of Beasley Lake. The Moorhead station provided the longest nearby climate record

Table 1. Global Climate Models (GCMs) used in this study; for more information on specific models and the CMIP5 project see Taylor et al. (2012) and Moss et al. (2010).

Modeling Center or Group	Model Name(s)	Equilibrium Climate Sensitivity (°C)	Transient Climate Response (°C)
Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1	2.8	1.7
National Center for Atmospheric Research	CCSM4	2.9	1.8
Community Earth System Model Contributors	CESM1(CAM5)	n.a.	2.3
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-Mk3.6.0	4.1	1.8
The First Institute of Oceanography, SOA, China	FIO-ESM	n.a.	n.a.
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	4.0	2.0
	GFDL-ESM2G	2.4	1.1
	GFDL-ESM2M	2.4	1.3
NASA Goddard Institute for Space Studies	GISS-E2-R	2.1	1.5
National Institute of Meteorological Research/Korea Meteorological Administration	HadGEM2-AO	n.a.	n.a.
Met Office Hadley Centre	HadGEM2-ES	4.6	2.5
Institut Pierre-Simon Laplace	IPSL-CM5A-LR	4.1	2.0
	IPSL-CM5A-MR	n.a	2.0
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC-ESM	4.7	2.2
Norwegian Climate Centre	NorESM1-M	2.8	1.4

with over 30 years of weather data, which was required to produce stable weather generation statistics for SYNTOR.

ANNAGNPS MODEL DESCRIPTION

The AnnAGNPS model was developed to simulate long-term estimates of water, sediment, and chemical transport in ungauged agricultural watersheds and to simulate effects of management alternatives (Bingner et al., 2015). The model operates at a daily time step and user-controlled spatial variability. The watershed is represented by sub-catchments (referred to as cells), which are hierarchically connected by concentrated flow (referred to as reaches). Cells can be delineated using topographic information or manually by the user and are defined based on assumed homogeneous soil and land-use properties. Runoff, sediment, and pollutants transported out of each cell are routed into user or topographically-defined reaches. Runoff from each cell is estimated based on the Soil Conservation Service curve number (CN) method (USDA Soil Conservation Service, 1985) and evapotranspiration (ET) is estimated using the Food and Agricultural Organization of the United Nations (FAO) dual crop coefficient procedure based on the Penman-Monteith equation (Allen et al., 1998). AnnAGNPS integrates technology from the Revised Universal Soil Loss Equation (RUSLE) to simulate sheet and rill erosion, to account for land cover and management conditions, and to estimate the particle-size distribution of eroded sediments (Renard et al., 1997). RUSLE uses a location-dependent crop database to provide estimates of root mass, canopy cover and fall height at various points throughout the growing season (Renard and Ferreira, 1993). Sediment delivery is estimated using the Hydro-geomorphic Universal Soil Loss Equation (HUSLE) (Theurer and Clarke, 1991) and the Bagnold equation is used to determine sediment transport capacity of the streams (Bagnold, 1966). Required climate inputs for AnnAGNPS include daily precipitation, minimum and maximum air temperature, dew point, wind speed, and solar radiation.

STUDY AREA AND MODEL INPUTS

Beasley Lake Watershed (BLW) is a small catchment (625 ha) located in an agriculturally intensive area of the Delta within Sunflower County, Mississippi (fig. 1). The drainage area is flat, with a maximum relief of 8.6 m from the highest point in the watershed to the lake. Runoff flows from fields into a network of agricultural drainage ditches, riparian channels, and finally into Beasley Lake, an oxbow lake located next to the Sunflower River. The watershed is divided into three major land-use types: 349 ha of row cropland, consisting primarily of soybean cropland since 2002, 85 ha of Conservation Reserve Program (CRP) land, and 140 ha of forest/riparian wetland. Water quality has been monitored in Beasley Lake since the mid-1990's as part of the Mississippi Delta Management System Evaluation Area (1994-2004) and the USDA Conservation Effects Assessment Program (CEAP; 2003-Present) (Nett et al., 2004; Lizotte et al., 2014). More detailed information on BLW can be found in Locke et al. (2008).

Model inputs were extracted from the USDA-Natural Resource Conservation Service (NRCS) National Soil Information System (NASIS) soil database, a hydrologically-corrected 1.5 m resolution digital elevation model (DEM) derived from LiDAR, and a field boundary land-use layer with a detailed record of agricultural management practices on a field by field basis from 1995 to present. Cells were delineated manually based on historical fields within the watershed and parameterized with topographic information derived from the DEM (Yuan et al., 2008). The dominant soil type was selected to represent each cell. For land-use, the model inputs were simplified to only represent land use and management practices from 2008, which for cropland consisted of 189 ha reduced tillage soybeans and 159 ha no-tillage soybeans (respective management schedules simulated in AnnAGNPS are detailed in table 2). These historical land-use conditions were used in all model simulations except those with altered management; therefore, these conditions can be considered the baseline scenario. Precipitation and temperature inputs were generated using SYNTOR as previously described. Dew point, wind speed, and solar radiation were generated using AgGEM, a weather generator program linked with AnnAGNPS (Johnson et al., 2000).

MODEL VALIDATION

AnnAGNPS has been successfully used to accurately predict runoff and sediment in a variety of watersheds (Yuan et al., 2001; Baginska et al., 2003; Suttles et al., 2003; Licciardello et al., 2007; Yuan et al., 2008). For example, AnnAGNPS-simulated monthly runoff and sediment were well correlated with observed values in Deep Hollow Lake watershed, also located in the Delta region of Mississippi (r^2 =0.9 for runoff on an event basis and 0.7 for monthly sediment; Yuan et al., 2001). AnnAGNPS has also been previously applied to the BLW where runoff and sediment were simulated satisfactorily (according to standards set forth in Moriasi et al., 2007) at the event scale from 1996-

Table 2. Management schedule for practices applied to GCM scenario simulations of soybean cropland in AnnAGNPS.[a]

Conventional Tillage	Reduced Tillage	No Tillage	Double Crop – Winter Wheat and Soybean	Cover Crop – Weeds
4/10: bedder/hip	4/10: bedder/hip	4/18: plant	2/12: fertilize with nitrogen	4/13: kill vegetation
4/18: plant	4/18: plant	10/6: harvest	6/5: harvest wheat	4/14: disk
10/6: harvest	10/6: harvest		6/6: burn stubble	4/16: bedder/hip
10/16: subsoiler; 30% residue left	11/5: disk		6/10: plant SB	4/18: plant
11/5: disk			10/6: harvest SB	10/6: harvest
			10/10: disk	10/15: begin volunteer growth of weeds
			10/14: do-all	
			10/15: plant wheat	

[a] Annual cycles repeat for the 200 years; the baseline scenario utilized the reduced and no tillage management schedules for 189 and 159 ha, respectively, to represent watershed conditions in 2008.

2002; Nash-Sutcliffe coefficient of efficiency was 0.81 for runoff and 0.54 for sediment from individual events without calibration (Yuan et al., 2008). As the BLW is a small watershed, event-based runoff is dominant with little to no baseflow during dry periods. In the current study, the same simulation databases utilized to successfully generate the BLW AnnAGNPS simulation in Yuan et al. (2008) were used with few modifications to expand the simulation period through 2014 and to include slight changes in the overall watershed area (but no change to the evaluated source area for runoff and sediment validation), higher resolution elevation data, updated soil profiles, and more detailed land management data from 1995-2014. AnnAGNPS parameters were determined with the best available information derived from field visits and expert knowledge of scientists working in the watershed for decades.

Predicted watershed loads entering the lake were the focus of this study, yet there were not adequate gauged records for flows entering the lake. However, there were records of lake nutrient and sediment concentrations from 2001 to present using bi-weekly grab samples. To evaluate simulation results on a qualitative basis, average monthly in-lake concentrations were plotted with estimated monthly runoff concentrations of nitrogen, phosphorus, and sediment to evaluate general trends (see figs. 2-4). Modeled monthly averages were calculated using daily model-generated

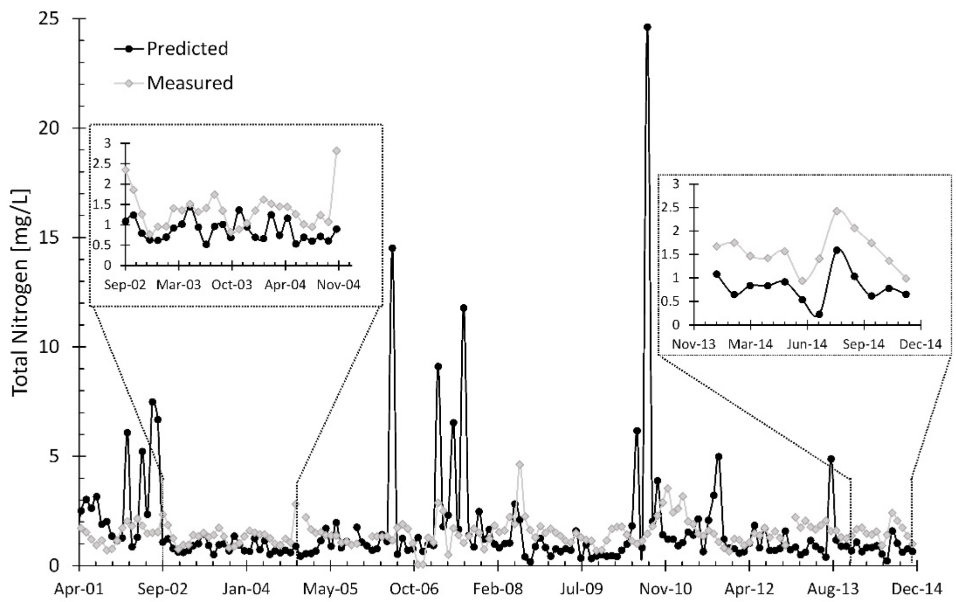

Figure 2. Average monthly total nitrogen concentrations measured in Beasley Lake (grey diamonds) and predicted in runoff entering lake by AnnAGNPS (black circles). Time periods at the beginning and end of the modeling time period are expanded to show that there are periods when the model-predicted concentrations track the same trend as the measured lake concentrations.

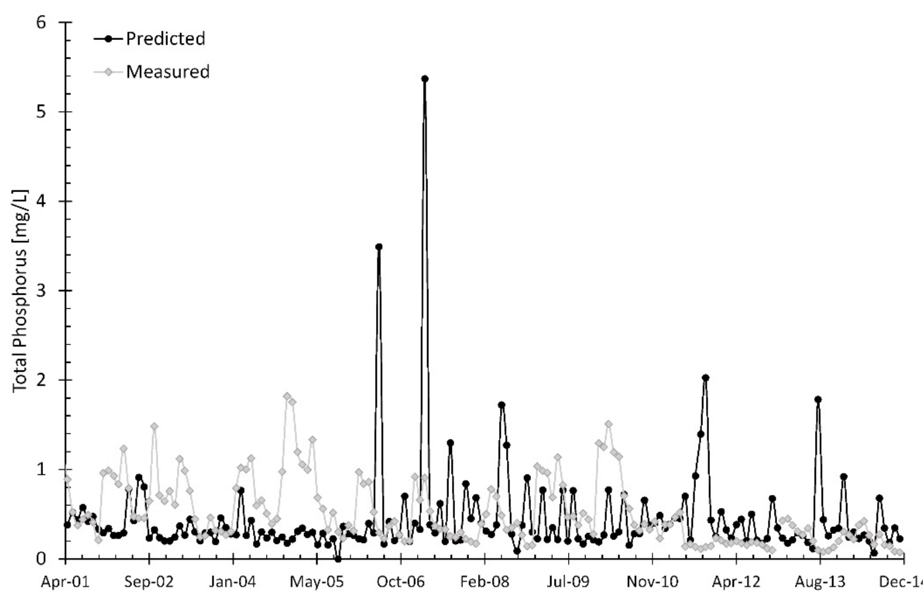

Figure 3 Average monthly total phosphorus concentrations measured in Beasley Lake (grey diamonds) and predicted in runoff entering lake by AnnAGNPS (black circles). Total phosphorus concentrations predicted in runoff do not reflect the patterns of concentrations measured in the lake.

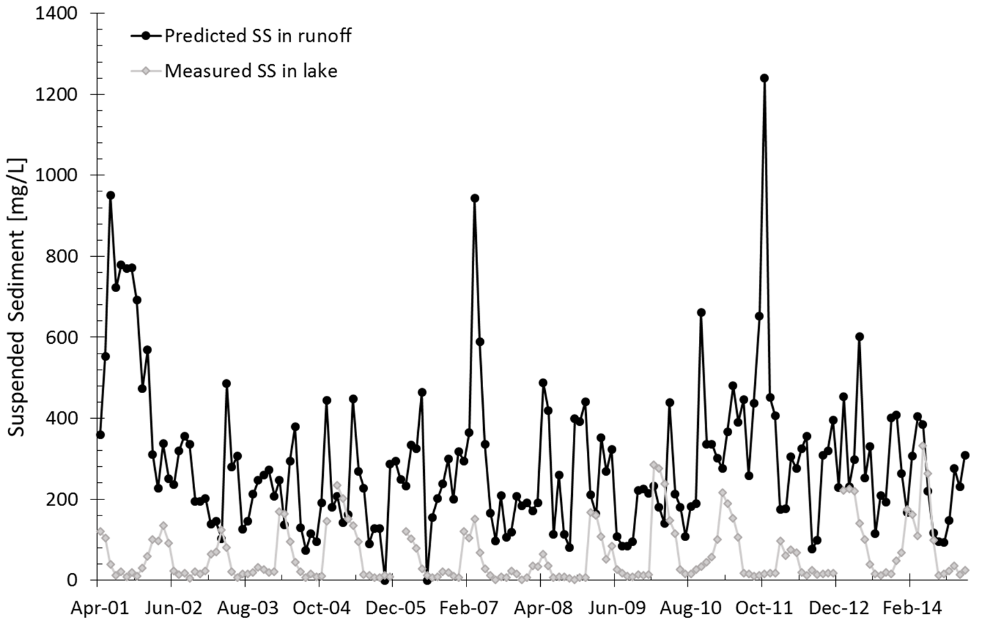

Figure 4 Average monthly suspended sediment concentrations measured in Beasley Lake (grey diamonds) and predicted sediment concentrations in runoff entering lake by AnnAGNPS (black circles).

values, observed monthly averages were calculated using data provided from bi-weekly grab samples. Values of runoff and lake nutrient or sediment concentrations cannot be compared directly as there are various physical, biological, and chemical processes occuring in the lake environment that are not captured by the AnnAGNPS model, including sedimentation, nutrient uptake and nutrient additions from leaf litter and organisms. The timing of peaks in predicted sediment concentrations and observed sediment concentration (fig. 4) are fairly synchronized, but the magnitudes cannot be compared as sediment settling occurs in the lake. In-lake total nitrogen concentrations were typically higher than AnnAGNPS-estimated runoff concentrations, with the exception of large concentration spikes in the simulated record that occurred with large rainfall events occuring in months with low average runoff. There were several periods when the measured in-lake and simulated runoff total nitrogen trends match quite well, with a slight offset (fig. 2). The phosphorus trends are quite different in the lake compared to simulated runoff concentrations. In the earlier part of the lake record (2001-2010) there is an osscilation between low and high phosphorus concentrations until 2011 when concentrations remain stable at lower concentrations. Phosphorus cycling in lakes is a highly dynamic process, with biological and sedimentary feedbacks, and it is unlikely that in-lake concentrations would match runoff concentrations (Sondergaard et al., 2003). Some of the factors influencing Beasley Lake nutrient trends include land-use patterns and precipitation (Lizotte et al., 2017). In general model-predicted runoff nutrient concentrations are within the same range as measured lake nutrient concentrations, which provides confidence that AnnAGNPS is representing the processes well enough to assess the relative differences between simulations. Due to the uncertainty in esimated nutrient runoff concentrations, the climate change simulation results are meant to be comparative and should not be interpreted as absolute predictions.

Simulation of Conservation Practices

Various agricultural management practices, including conventional tillage, reduced tillage, no tillage, double crop of summer soybean and winter wheat, and a weed cover crop were simulated to determine their impact on loads of total nitrogen (TN), total phosphorus (TP) and total suspended sediment (TSS). The different practices simulated for each management schedule are shown in table 2. The parameters defined for simulating the different tillage and conservation practices used in these scenarios were developed based on long-term management data for the BLW.

Conservation practices were simulated using climate inputs from four GCMs: FIO-ESM and GISS-E2-R, HadGEM2-ES, and IPSL-CM5A-MR. These four models were selected because they represented a high level of variability with respect to minimum temperature (Tmin), maximum temperature (Tmax), or precipitation projections, as shown in figure 5. FIO-ESM had the lowest Tmin and Tmax projections and a medium-high precipitation estimate. GISS-E2-R also had low Tmin and Tmax projections, but the highest precipitation projection. HadGEM2-ES had the highest Tmax projection, but average Tmin and medium-low precipitation projections. IPSL-CM5A-MR had average Tmin and Tmax projections but the lowest precipitation estimates. The variation between the models will help to exemplify the greatest range in potential outcomes. The results from AnnAGNPS simulations with each GCM were combined to evaluate the effectiveness of conservation practices on reducing water quality loads into Beasley Lake.

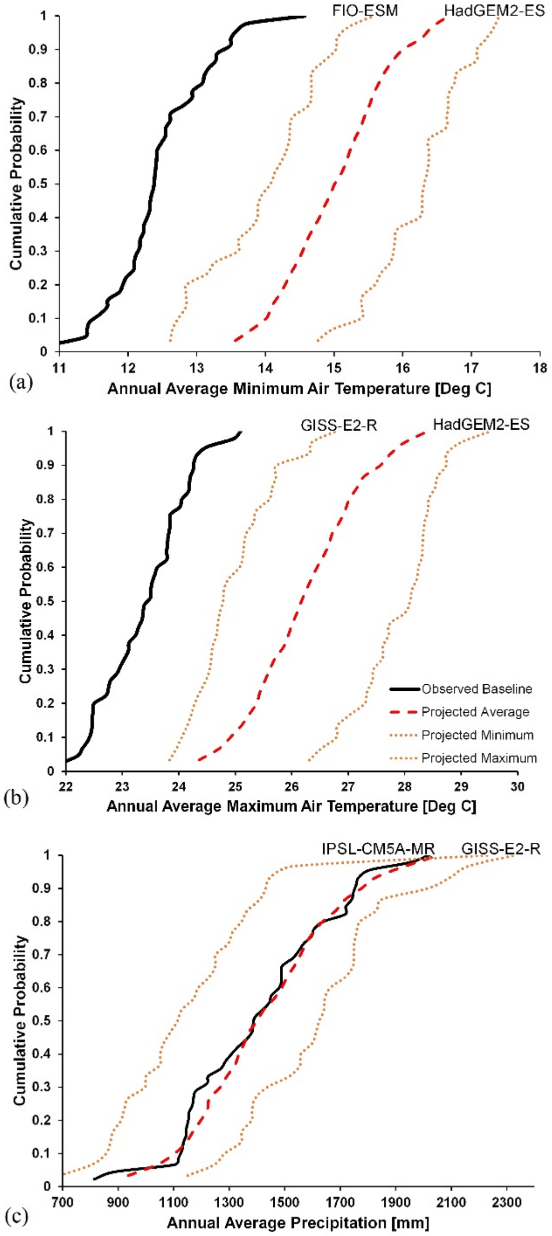

Figure 5. Cumulative probability plots of annual average minimum temperature (A), maximum temperature (B), and precipitation (C) projections from the GCMs used in this study. Observed historical data (black line), projected average GCM projections (i.e., ensemble; red line), and minimum and maximum GCM projections (orange dashed line) are shown. The name of the GCM producing the minimum or maximum projection are shown on the figure.

Results

Analysis of Projected Climate Estimates

The results of 15 GCMs were averaged to provide an ensemble projection of temperature and precipitation. The resulting ensemble of projected annual average minimum and maximum temperature were on average 2.6°C and 2.9°C higher than historical temperature averages of the 1971-2015 time period; these differences were statistically significant with a p-value < 0.001 estimated using Welch's t-test (table 3). There was no significant difference between historical and projected precipitation; however, there was a great deal of variability in the range of annual average projected values (689-2330 mm). The greatest increase in average temperature occurred during the summer (June-August) and the growing season (April-September); however, these seasons had little increase in total precipitation (table 4).

Table 3. Average annual minimum and maximum temperature and precipitation for historical (1971-2015) and projected (2041-2070) climate.[a]

Annual Average	Historical 1971-2015	Projected 2041-2070	p-value
Minimum temperature (°C)	12.5 ± 0.7 (10.9-14.6)	15.1 ± 1.0 (12.3-17.6)	<0.001
Maximum temperature (°C)	23.4 ± 0.8 (21.9-25.1)	26.3 ± 1.3 (22.8-30.1)	<0.001
Precipitation (mm)	1410 ± 268 (814-2020)	1440 ± 300 (689-2330)	0.65

[a] p-value resulting from Welch's t-test with historical and projected values; values shown are average ± standard deviation with the range of values shown in parentheses.

Impacts of Climate Change on Water Quality Loads

The ensemble of climate change simulations with 15 GCMs estimated a decrease in average annual runoff with projected median (50% probability) runoff approximately 9.6% (29,000 m^3) less than the historical simulated median ($p=0.004$ using Welch's t-test). There was a statistically significant increase in projected TSS loads with median values approximately 12% greater (80 metric tons/year; $p=0.03$) and median TP loads 9.2% greater (50 kg/year; $p=0.04$) than historical simulated values. However, while there was an increase of 9.6% (200 kg/year) in median TN loads it was not statistically significant ($p=0.17$). The uncertainty in the upper-tail of the probability distributions increased for TSS, TN, and TP loads with more variability observed at a cumulative probability greater than 0.9 compared to the 0.5 cumulative probability (fig. 6).

Runoff is lower for all months except January and March, with the greatest decreases in May, June, July, and October. The largest increases in loads of TSS, TN, and TP were in January and March when projected runoff increased. Overall, concentrations of TSS, TN, and TP in runoff are higher for all months with climate change compared to the historical simulations (table 5). The elevated nutrient and sediment loads with reduced runoff suggest that larger loads are generated from more intense precipitation events. One parameter that can help to understand the change in intensity is the rainfall erosivity (R) value within the RUSLE equation, which is the average annual total of individual storm erosivity (EI) values. In AnnAGNPS, EI is determined for each individual storm event using the unit rainfall distribution along with the event rainfall to determine a 30 minute intensity (I) and associated storm event energy (E), using methods described in Brown and Foster (1987) and the RUSLE handbook (Renard et al. 1997). The median R value produced from AnnAGNPS using 200-year simulations with GCM climate inputs was 7693, which is slightly higher than the median R value generated using historical climate information, 7181, but this is not statistically significant at the $p=0.05$

Table 4. Seasonal average temperature, total precipitation, and total evapotranspiration for the historical data record (1971-2015) and projected climate from 15 GCMs (2041-2070).

	Average Temperature [°C]			Total Precipitation [mm]			Evapotranspiration [mm][b]		
	Historical	Projected	Diff.[a]	Historical	Projected	Diff.	Historical	Projected	Diff.
Winter	7.68	9.96	+2.4	396	404	+8	105	135	+30
Spring	18.0	20.5	+2.5	406	411	+5	271	303	+32
Summer	27.3	30.6	+3.3	285	288	+3	231	252	+21
Fall	18.6	21.5	+2.9	323	336	+13	151	171	+20
Growing season[c]	24.5	27.6	+3.1	644	649	+5	582	640	+58

[a] Diff. is the difference between projected – historical values.
[b] Evapotranspiration estimates are from AnnAGNPS.
[c] Growing season refers to April – October.

level (p=0.09 using Welch's t-test; R units are MJ ∘ mm ∘ ha^{-1} ∘ h^{-1} ∘ y^{-1}; fig. 7). The majority of GCM simulations had a greater number of wet days per year than the historical simulation and also many had a higher average daily precipitation rate for the top 100 events in each time series (fig. 8). The increased number of wet days, along with higher precipitation rates may attribute to the higher loads observed in the projected climate simulations.

EFFECTIVENESS OF CONSERVATION PRACTICES WITH CHANGES IN CLIMATIC PATTERNS

The baseline simulated average annual water quality loads with historical climate inputs were approximately 5000 m^3/ha for runoff, 1.5 tons/ha for sediment yield, 3.7 kg/ha nitrogen, and 1.0 kg/ha phosphorus. With projected climate change and soybean cropland with either conventional or reduced tillage management the average loads of TSS, TN, and TP increased. The largest increases were in TN loads, which were 32% greater with conventional tillage and 24% greater with reduced tillage. Conversely, no-tillage reduced loads of TSS, TN, and TP by 47%, 34%, and 20%, respectively. Covering the soil from late-fall to early spring outside of the growing season was even more effective at reducing water quality loads: planting wheat or a cover crop was effective at reducing TSS by about 60% and TP by 26%-

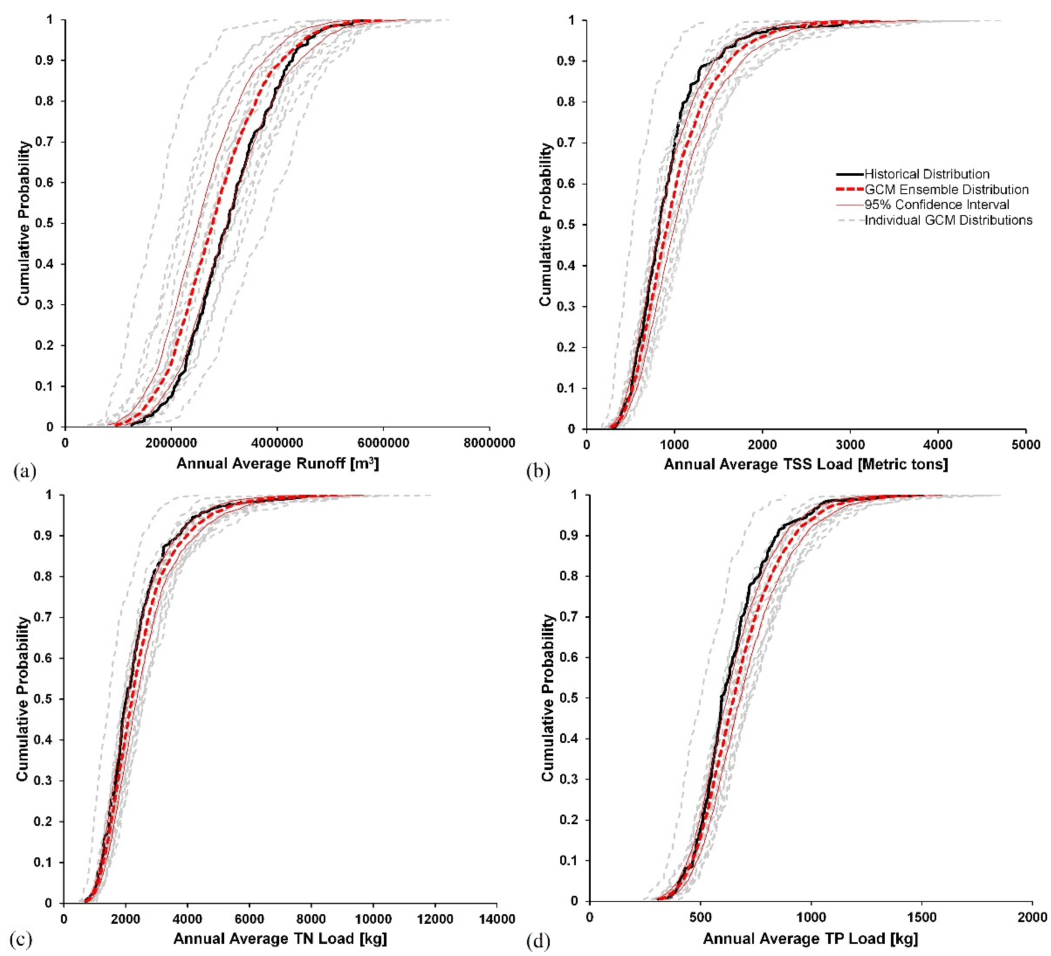

Figure 6. Cumulative probability distributions for historical and projected average annual runoff (a), TSS loads (b), TN loads (c), and TP loads (d). Historical distributions are shown with a black line, projected GCM-ensemble distributions are shown with a dashed red line, with the 95% confidence interval indicated. The results from individual GCM distributions are also shown as grey-dashed lines to demonstrate the variability in loads estimated from the different GCM models.

Table 5. Percent differences in average monthly runoff and water quality average monthly loads and concentrations between the GCM ensemble simulations and historical simulation in AnnAGNPS.[a]

		TSS		TN		TP	
	Runoff	Load	Conc.	Load	Conc.	Load	Conc.
January	**4%**	**36%**	**30%**	**30%**	**25%**	**40%**	**37%**
February	-8%	**11%**	**20%**	**11%**	**21%**	**24%**	**37%**
March	**3%**	**24%**	**19%**	**20%**	**16%**	**45%**	**41%**
April	-7%	**9%**	**14%**	**6%**	**12%**	**20%**	**38%**
May	-20%	-5%	**19%**	-7%	**18%**	**22%**	**44%**
June	-17%	**1%**	**23%**	**1%**	**25%**	**10%**	**43%**
July	-16%	**1%**	**19%**	-2%	**19%**	**1%**	**32%**
August	-12%	**14%**	**36%**	**9%**	**32%**	**5%**	**30%**
September	-5%	**13%**	**20%**	**11%**	**18%**	**12%**	**21%**
October	-15%	**6%**	**26%**	**3%**	**24%**	**10%**	**37%**
November	-9%	**10%**	**21%**	**6%**	**17%**	**22%**	**40%**
December	-11%	-1%	**11%**	-7%	**6%**	**19%**	**41%**
Annual	-8%	**11%**	**20%**	**7%**	**17%**	**24%**	**38%**

[a] Bold values indicate increases from baseline.

30%. An unfertilized cover crop was also effective at reducing TN by about 75% below baseline historical levels. A fertilized double crop, like winter wheat, increased TN loads by an average of 167% compared to the baseline simulation that is represented by only unfertilized soybean cropland (table 6). The median and 10th/90th percentiles from conservation practice simulations are shown in the box plots in figure 9.

DISCUSSION

According to an ensemble of 15 of the CMIP5 GCMs, climate change in the western region of Mississippi may include a rise in average temperature from 2.4°C in winter to 3.3°C in summer. Annual precipitation on average may not be statistically different from historical amounts; however, the rainfall patterns are expected to shift with more rainfall in winter and fall months. In general, with temperatures rising by 2°C-3°C and no substantial increase in precipitation, there could be additional stress on agricultural water management systems with rising water deficits due to higher evapotranspiration. This study estimated an increase in evapotranspiration over all seasons with an average increase of 58 mm during the growing season, which may increase the need for irrigation. This trend can be extrapolated to the Delta region of Mississippi, where declining aquifer water levels are of concern (Arthur, 2001). In addition, predicted runoff with climate change decreased in most months; the maximum decreases in projected runoff occurred in May through July, with the largest decrease in May (-20%). Despite the decline in runoff, sediment, nitrogen, and phosphorus loads increased with projected climate change an average of 12%, 9.6%, and 9.2%. It's hypothesized that the increase in loads is due to increased rainfall intensity observed in the projected simulations. These results are similar to those found by Jayakody et al. (2014), which found maximum changes with climate change of 22%, 7.3%, and 9.2% for sediment, nitrogen, and phosphorus yields from the Upper Pearl River Watershed in Mississippi for the 2046-2065 time period. The Jayakody study used only the CCSM3 model to estimate future climate change.

The results from this study suggest that adaptation to future climate regimes will require additional emphasis on effective conservation practice placement and management. With projected increases in sediment and nutrient loads, practices such as reduced or no-tillage and cover crops can offset these increases or even reduce loads from soybean cropland beyond historical levels. The modeling results demonstrated a decrease in sediment and nutrient loads as residue or plant cover increased, with the lowest loads occurring when winter cover was simulated. Reductions in soil erosion can be expected as residue cover increases; some studies suggest even 20% residue cover can lead to a 50% decrease in soil erosion and 60% or greater residue cover can

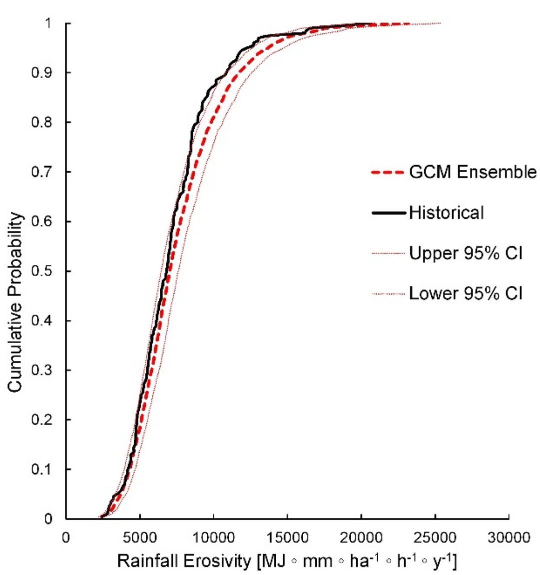

Figure 7. Cumulative probability distribution of rainfall erosivity estimates generated from the AnnAGNPS model. GCM ensemble distribution is shown in red with the 95% confidence interval, which can be compared to the historical distribution in black.

Table 6. Differences in runoff, and loads of TSS, TN, and TP between the baseline (i.e., historical climate) simulation and climate change simulations with various management practices.[a]

	Percent Difference			
	Runoff	TSS	TN	TP
Soy conventional tillage	*-12%*	+28%	+32%	+18%
Soy reduced tillage	*-12%*	+17%	+24%	+13%
Soy no tillage	*-11%*	*-47%*	*-34%*	*-20%*
Soy-winter wheat double crop	*-12%*	*-59%*	+167%	*-26%*
Soy with cover crop	*-13%*	*-60%*	*-75%*	*-30%*

[a] Values in italics highlight decreases from baseline.

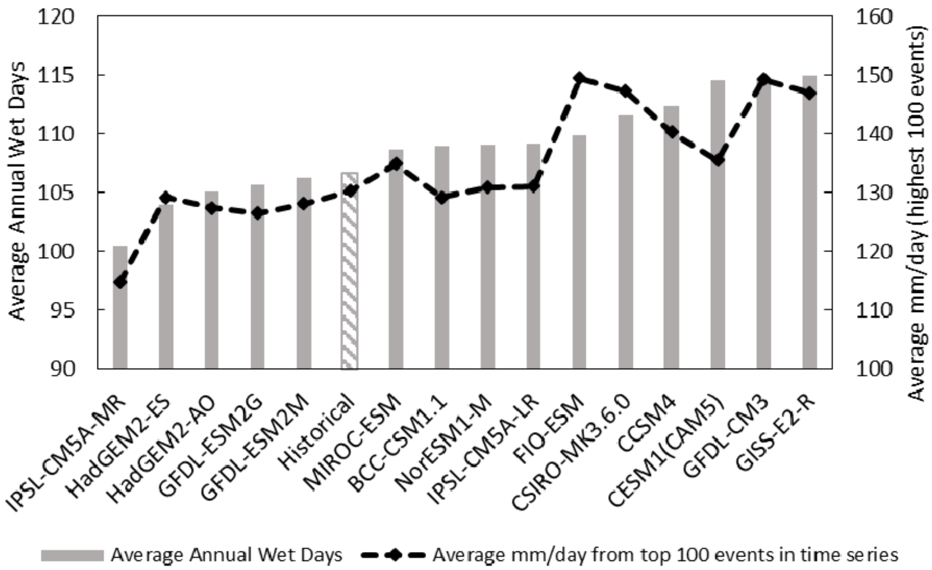

Figure 8. Average annual number of wet days, or days with precipitation, and the average daily rainfall (mm/day) of the highest 100 events in the 200-year time series for the historical simulation, as well as each GCM used in this study.

result in 80% or greater reduction in erosion (Morris et al., 2010). Soils covered by crop residue or cover crops will be protected from raindrop impacts and, therefore, there will be less detachment of soil particles (Young and Wiersma, 1973). Cover crops have additional benefits beyond soil erosion protection as they also scavenge residual soil nitrogen (Dabney et al., 2001). The degree of soil disturbance influenced the sediment and nutrient loads in the simulations without winter cover. Loads decreased from conventional tillage to conservation tillage to no tillage, as each simulated management system generated less soil disturbance and thus less detached soil particles available for transport. Field and plot-scale research from the Mid-South region also provide evidence that reduced tillage practices are effective for reducing erosion in soybean fields (Locke et al., 2010).

Other model simulation studies concur with the results of this study. Garbrecht and Zhang found that double cropping or no till practices can reduce annual soil erosion on winter wheat cropland in Oklahoma below historical levels even with the added impact of climate change (Garbrecht and Zhang, 2015). Parajuli et al. (2016) found slight reductions in sediment yield with reduced tillage practices, as compared to conventional tillage, on soybean and corn cropland in the Sunflower River watershed in Mississippi, but additional practices such as double cropping and no-till were not examined. Experts estimate that additional benefits of conversion of conventional tillage to either conservation tillage or no-till, or the use of cover crops could include reduced use of fuel, improved carbon sequestration, increased economic returns, and improved adaptation to climate change (Delgado et al., 2011).

Additional adaptation strategies to climate change could include altering planting and harvesting dates to account for longer growing seasons and faster crop development (Alexandrov and Hoogenboom, 2000). Changes in planting and harvesting dates are difficult to predict as they will be highly dependent on local weather. While the projected temperature in Mississippi in early March might be suitable for planting soybeans, projected high March precipitation may prevent farmers from accessing their fields for planting. The effects of altered planting and harvesting dates were not explored in this study. Other management practices such as vegetative filter strips, riparian buffer strips, nutrient management, constructed wetlands, sediment retention ponds, and/or tailwater recovery could be beneficial for reducing the loads of sediment and nutrients transported downstream or into local water bodies. Jayakody et al. (2014) found that vegetative filter strips were highly effective for reducing loads of sediment, nitrogen and phosphorus with climate change, but that nutrient management of manure applications was also effective for reducing nitrogen and phosphorus loads.

Climate change impacts on soybean cropland were the emphasis of this study. However, the effects of increased CO_2 and air temperature on crop development and yield were not considered. Common crops in the Mississippi Delta region, including rice, soybeans, and cotton, all use C_3 pathways for carbon fixation, which means that these crops become less efficient as air temperature rises or water is limiting. In contrast, C_4 crops such as corn, sugar cane, or sorghum are better adapted for water stress and rising temperatures (McNulty et al., 2015). However, C_3 plants may benefit from CO_2 fertilization more than C_4 plants (Sage and Kubien, 2003). Despite this, Parajuli et al. (2016) found that predicted soybean yield in the Sunflower River Basin in Mississippi decreased by 1.5%-3% with climate change due to heat stress from extreme temperature fluctuations.

This study utilized climate projection results generated from 15 GCMs forced with the 8.5 W/m^2 RCP during the 2041-2070 time frame. The variation between the 15 GCM scenarios provided an estimate of uncertainty when evaluating climate change projections as they represent a broad range of potential projected climate (Garbrecht et al., 2016); however, these are not comprehensive of all possible future scenarios. Modeling results could vary if using data from the 2.6, 4.5, or 6 W/m^2 RCPs that generate different temperature and precipitation projections. The time frame studied could

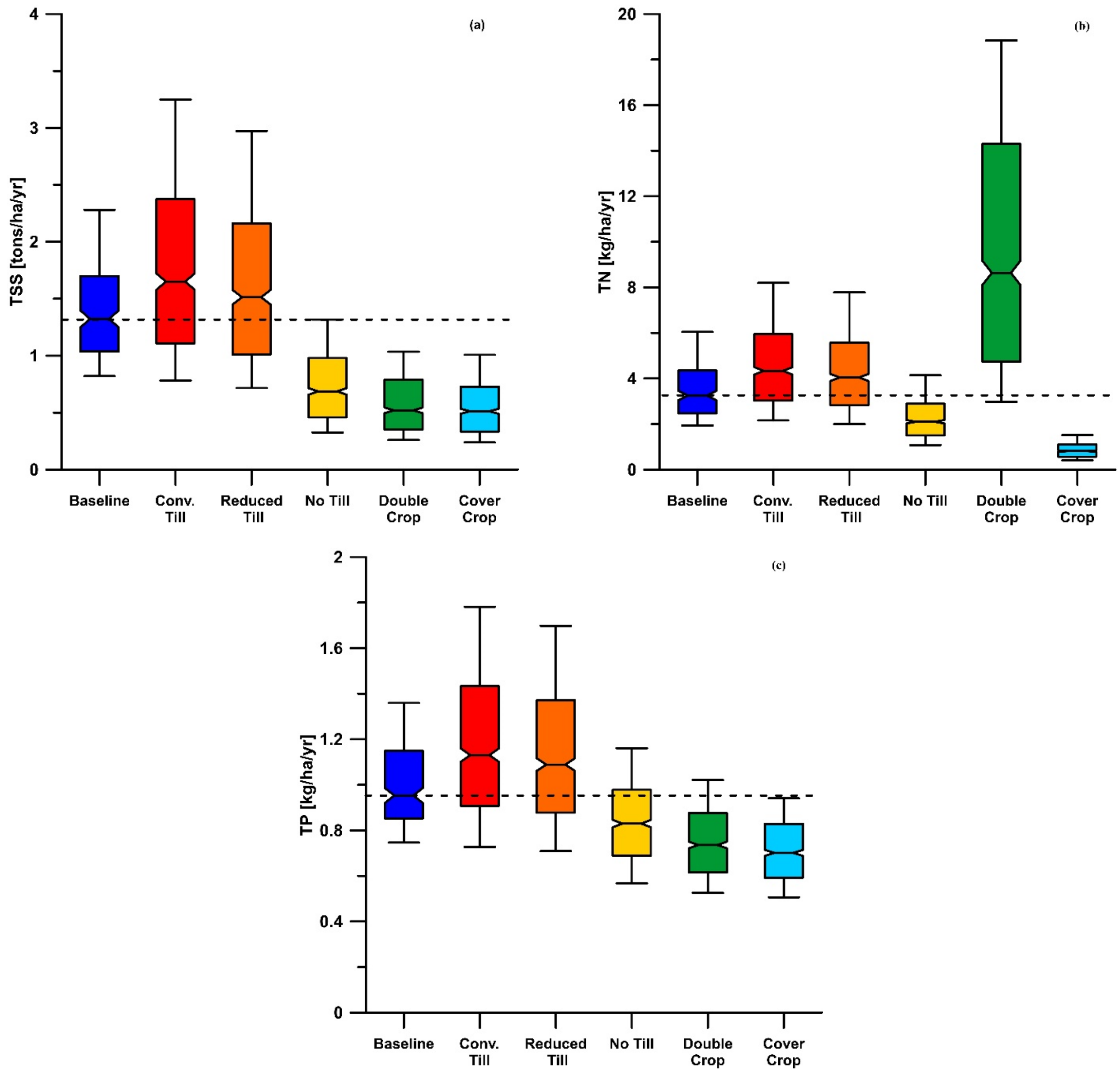

Figure 9. Results represent the range of export ratios in TSS (a), TN (b), and TP (c) expected with climate change and various best management practices (BMPs) applied to soybean cropland. The baseline range in export ratios generated from historical climate inputs can be compared with export ratios simulated from conventional tillage (Conv. Till), reduced tillage, no tillage (no till), double crop (winter wheat and soybean), and a weed cover crop. Median baseline export ratios are shown with a dashed line. Box plot lines show 10th, 25th, 50th, 75th, and 90th percentiles.

also potentially change the outcome of the results. Yet, the goal of this study was not to evaluate all potential outcomes with projected climate, nor to provide quantitative forecasts, but instead to develop an understanding of relative climate impacts on agricultural watersheds and water quality loads in the Lower Mississippi River Basin by comparing to historical simulations. Future studies may address other aspects of this work, for example inclusion of additional RCP scenarios or by changing the spatial and/or temporal scale used for analysis.

CONCLUSIONS

Successful adaption to climate change in the agricultural sector will require the use of conservation practices that are effective across a broad range of potential climate conditions. Intensive agricultural watersheds in the Lower Mississippi River Basin are important areas to study due to their contributions to national and global crop production, as well as national water quality problems, such as the Gulf of Mexico hypoxia. This area also represents distinctive geographic and climatic conditions, which differ from other highly studied agricultural areas such as the upper Midwest. The results of this study can be useful for scientists or managers studying how to improve water quality in agricultural watersheds through the use of best management practices or how to manage for potential climate impacts in this region.

According to results of the 15 GCMs utilized in this study, average monthly temperatures are expected to rise by 2°C-3°C by 2041-2070 in the Delta region of Mississippi;

however, the ensemble of GCM results do not show a statistically significant departure from historical average annual precipitation values. Higher temperatures resulted in an increase in evapotranspiration, which when combined with historically-similar precipitation levels caused a reduction of 9.6% in median average annual runoff. Despite a reduction in runoff, median projected loads of sediment, phosphorus, and nitrogen increased 11.6%, 9.2%, and 9.6%, respectively, with the ensemble climate change simulations. Modeling simulations suggest that higher contaminant loads were generated due to more intense precipitation events with greater rainfall erosivity. Despite increased loads from climate change, simulated conservation practices including no-till and cover crops were effective at maintaining sediment and nutrient export rates below historical baseline levels. Modeling results suggest that implementing these practices on a watershed scale can improve water quality conditions and prevent further degradation from future climate impacts. The implications for resource managers are that wider application of conservation practices will not only provide benefits for water quality and environmental resources today, but may pay additional dividends into the future.

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